DDF annual report

Title of Investigation:

Carbon Nanotubes for Gradient-Index Optics

Principal Investigator:

John C. Brasunas (Code 693)

Other In-house Members of Team (include Code):

None

Other External Collaborators:

None

Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2004 and Earlier Years:

$0

Funding Authorized for FY 2005:

$2,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: $1,340, for travel to Materials Research Society conference

Status of Investigation at End of FY 2005:

To be continued in FY 2006, with additional $2,000 in FY 2006 DDF funding; also supplemented by Core Capabilities funding

Expected Completion Date:

October 2006

Purpose of Investigation:

The purpose of this investigation is deciding whether the nanotechnology field provides new opportunities for developing anti-reflection (AR) coatings. Many optical instruments, including eyeglasses, microscopes, and telescopes, suffer from unwanted reflections. . Reflections occur when light suddenly goes from a medium in which it has one speed (e.g., vacuum) to a second medium (e.g., glass) in which it has another speed. Two ways to eliminate reflections include: (1) make a coating in which the speed of light varies smoothly from the one speed to the other (no sudden speed jump, no reflection); and (2) coat with tubes standing at the boundary and having length longer, and diameter shorter, than the wavelength of the light (this has been observed but is not fully understood). By reducing these reflections with AR coatings, we can build more efficient optical instruments. The end goal of the investigation continues to be a paper study, with a recommendation (if feasible) as to whether Goddard should perform the work in-house, buy the capability from an outside source, fund the research capability through a program such as the Small Business Innovation Research (SBIR), or some mixture of the three. A second goal is to see whether one of the coating techniques is more promising than the other.

Accomplishments to Date:

At the start of this investigation, I believed that anti-reflection (AR) coatings would be achieved by using carbon nanotubes (CNTs). Helped in part by attending the Spring 2005 Materials Research Society (MRS) conference, I came to realize that porosity (including nano-porosity) also was a candidate solution, particularly in view of the vigorous, ongoing research in porosity. Thus, I would now say that nanotechnology has two possible approaches to crafting broad-band AR coatings:

- ***Nanoporosity*** —Gradient-index (GRIN) optics via varying the porosity from the substrate to the embedding medium. This smoothly tunes the index from the substrate to the medium, eliminating reflection. This is nanotechnology because the pores have to be less than a wavelength (sub-micron for the near infrared), but need not involve nanotubes specifically.
- **CNT**— Fabricate a meta-material (structure smaller than a wavelength so that diffraction is suppressed) of vertically aligned CNTs, which, in addition to being sufficiently narrow, have a high-length/diameter (L/D) ratio needed for broad-band AR. Deep voids suppress reflection over a wide spectral range. CNTs have demonstrated a L/D ~ 1000 – 10 nm D, 10 μm L.

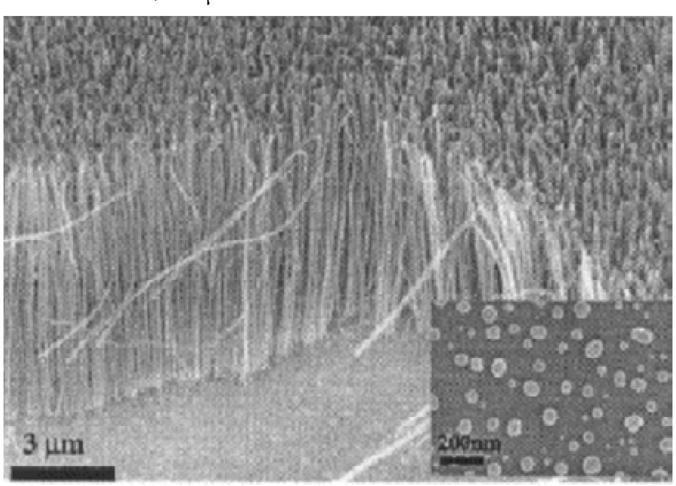

Figure 1. Aligned CNTs (Sevillano, TECNUN, 2003)

Some preliminary assessments for CNT and nanoporosity, respectively:

- CNT vertical alignment can be achieved via plasma-enhanced CVD (PECVD); the effect of negative high bias during microwave PECVD is significant. There is much research ongoing for electron-emission applications.
- Single-wall nanotubes may be desirable for smaller feature size, but L/D is probably limited to 70.
- Metallic CNTs may be desirable for higher conductivity.
- We need vertically aligned CNTs, with non-periodic spacing, to suppress diffraction.
- Recent reports show that vertically aligned CNTs do behave as miniature antennas.
- CNTs have appreciable self-adherence via van der Waals forces.
- A single-wall nanotube film/mat can be removed from a substrate and transferred to another substrate.
- NASA Johnson (Smalley *et al.*) has produced 1-cm^2 membranes of aligned CNTs.

- Nanoporosity research is vigorous, with some work in porous carbon.
- There may be possibilities in diamond-like carbon (DLC), perhaps by varying the sp2/sp3 different types of carbon bonding) ratio.
- There may be possibilities in aerogels or in fullerenes (a sort of molecular nanographite).

Planned Future Work:

- Attend another conference, probably domestic.
- Understand current capabilities with respect to nanoporosity.
- Understand current capabilities with respect to vertically aligned CNTs.
- Determine in-house, out-of-house mix for nano-oriented AR developments.
- Write final report, including recommendations for means of funding nanotechnology-enabled AR coatings. Sources include more Goddard and Headquarters funding, and support from small business.

Key Points Summary:

Project's innovative features: Using the unique features of nanomaterials (nanoporosity, nanotube geometry), we can make new materials with new properties. We can use these new properties to make new and better anti-reflection coatings.

Potential payoff to Goddard/NASA: This work is relevant to both Goddard and overall NASA Space Science strategic objectives. Improved AR coatings will improve the performance of infrared (IR) science instruments, including spectrometers. Improved science instruments will enhance the study of planetary surfaces and atmospheres, and thereby the study of pre-biotic molecules and the origin of life in a planetary system. A careful study of spectral features in our solar system, especially organic and volatile compounds, enables us to compare the gas giants with the terrestrial planets to better understand the evolution of a solar system. This also will strengthen our ability to interpret extrasolar planets. Strengthening our position in planetary instruments also is a goal at Goddard, which has a tradition of building planetary spectrometers.

The Voyager and Cassini missions provide a case in point. Indeed, Goddard's mission is "to expand knowledge on the Earth and its environment, the solar system, and the universe through observations from space."

The criteria for success: The success criteria will be to produce useful recommendations concerning what has to be done, and where it should be done, and possibly how it might be funded.

Technical risk factors: The risk would be the nanotechnology field is currently too far away to produce useful AR coatings in the near future. Given the very broad nature of nanotechnology research, the maturity level is difficult to assess comprehensively. Another concern is possible human health risks due to CNTs. In the context of optics, this might mean that precautions similar to those required when working with beryllium (a prime material for lightweight optics) might be needed.